



**Synergy of Diamond Turning  
& Computer Controlled Polishing  
In the Production of  
Multi-Mirror Precision Beryllium Systems**

**Presented at**  
**Mirror Tech Days, Space & Missile Defense Conference**  
**NASA Marshall Space Flight Center**

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# SBIR Description

## **LCKV Sensor Assembly 100% Beryllium Manufacturability Improvement Project**

- **Optimize beryllium kill vehicle sensor design for low cost manufacturing processes by minimizing**
  - end-to-end cycle times
  - processing costs
  - assembly/alignment times
- **Beryllium offers many performance advantages and is an excellent choice for high-performance sensor designs**

**MDA Phase I SBIR  
MDA Contract #HA0006-05-C-7175  
COR: Charles A. Pagel**

# Problem Statement

## Existing Production Processes Are High Cost for Intended Application

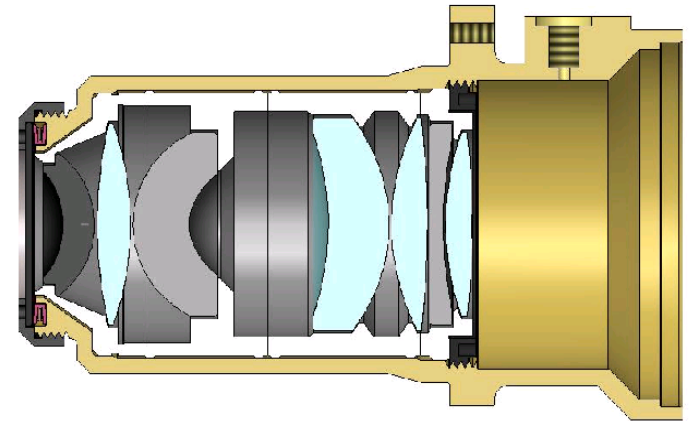
- **LCKV Multi-mirror Sensor Design**
  - High performance optical surfaces
  - Alignment to extremely tight tolerances
    - Centration errors  $< 6 \mu\text{m}$  (typical)
    - Tilt errors  $< 50 \mu\text{Radians}$  (typical)
- **Current Production Process**
  - Precision optical surfaces
    - Conventional polishing techniques
    - Optical surfaces loosely controlled relative to mechanical interfaces
  - Precision alignments
    - Accomplished manually after optical surface is complete

# Precision Machining & Diamond Turning As Precision Alignment Methodology

- **LightWorks Expertise**
  - Precision system alignment
  - Utilizing precision diamond turned interfaces
    - Multi-mirror reflective systems in visible & IR
    - Multi-element refractive systems in visible & IR
  - Achieving typical alignment tolerances
    - Centration Error < 2.5  $\mu\text{m}$
    - Tilt Error < 50  $\mu\text{Radians}$
    - No manual alignment required for “Snap Together” systems

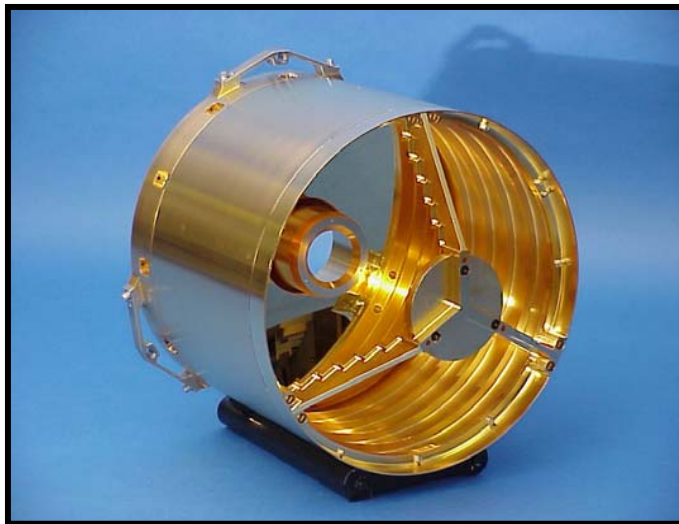
# Diamond Turning & Alignment Capabilities

- **Missile Launch Detection Optics**
  - Infrared Refractive materials
    - Three aspheric surfaces
  - Aluminum cells
  - Diamond turned assemblies
    - Element-to-element centration accuracy  $< 2.5\mu\text{m}$
    - Element-to element tilt accuracy  $< 100\ \mu\text{Radians}$
  - Production program
    - 90 units in production
    - Recently awarded contract for additional 230 units



# Diamond Turning & Alignment Capabilities

- **Airborne Observatory Telescope**
  - 14 inch all-aluminum reflective telescope
  - Diamond turned & post polished
  - Multi-spectral VIS / MWIR / LWIR
  - 2 units delivered





# Computer Controlled Polishing Capabilities

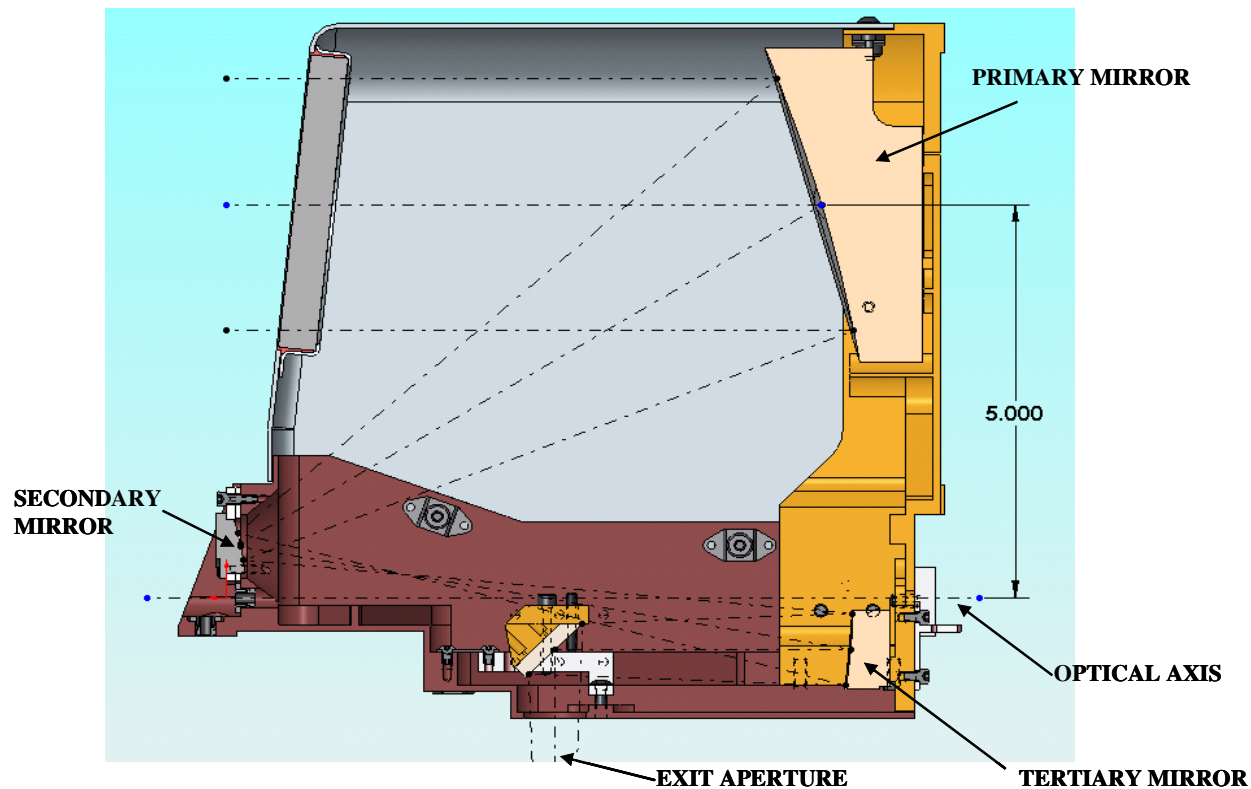
- **Zeeko/LOH Aspheric Polishing Machine**
  - 7-axis computer control
  - True, free-form polishing
- **Capabilities**
  - On-axis spheres & aspheres
  - Off-axis aspheres (on the machine axis)
  - On-axis and off-axis toroids
  - Free form optical surfaces
    - Conformal windows
    - Corrector plates
  - Polish directly from generated blanks
  - Wide range of substrate materials



# Glass Mirror Reflective TMA

- **Glass & Invar TMA**

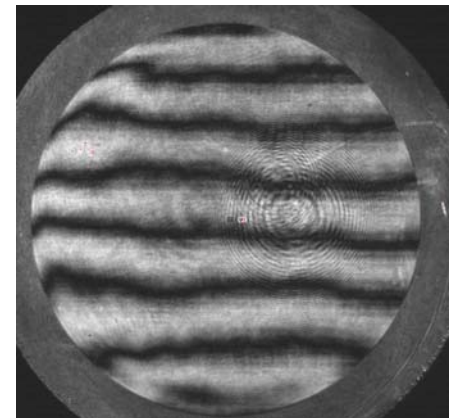
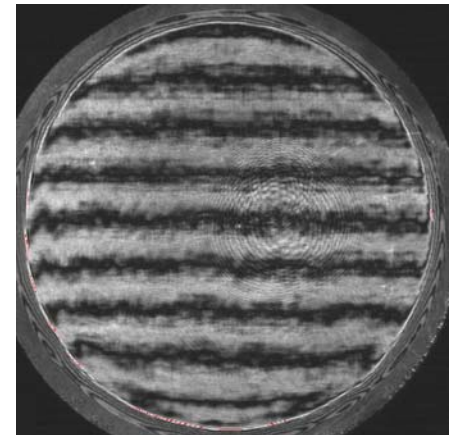
- Optical subsystem of a **government funded research project**
- Glass mirrors polished relative to alignment reference surfaces





# TMA Mirror Polish Results

- **Primary, 3.25 inch aperture, off-axis parabola**
  - All Mirrors Polished directly from generated blanks
  - Surface figure error  $< \lambda/8$  P-V @ 632.8nm
  - Surface slope error  $< 0.01$  waves/mm rms
  - Polished relative to alignment reference features



# Polish Process Video



# Computer-Controlled Polishing at LightWorks

## >> Looking Forward <<

- **Today**
  - Current CCP capacity is 200mm
- **October 2005**
  - LightWorks will take delivery of a 400mm capacity machine
- **April 2006**
  - LightWorks will take delivery of a 1.0 meter capacity machine

### **We continue to**

- ✓ Develop CCP process controls & feedback methodologies
- ✓ Improve CCP alignment maintenance processes & controls
- ✓ Improve methods for referencing optical surfaces to mechanical interfaces

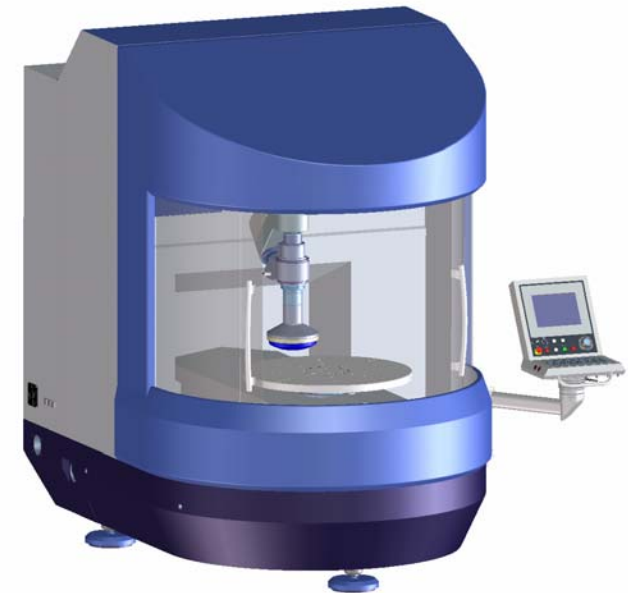
# Combining the Two Technologies

## GOAL

**Exploit the synergy of diamond turning & computer controlled polishing capability under one roof.**



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# SBIR - Combining the Two Technologies

## • Single Point Diamond Turning

- Deterministic figuring of optical surfaces & hardware interfaces relative to fixed machine reference points
- Alignment accuracies only limited by runout of translation airslides and airbearing spindle
- Typical accuracies
  - Centration error < 2.5  $\mu\text{m}$
  - Tilt error < 50  $\mu\text{Radians}$

## • 7-axis computer controlled polishing machine

- Single point computer controlled polishing
- Deterministic polishing of optical surfaces relative to fixed machine reference points
- Typical accuracies
  - Centration error < 2.5  $\mu\text{m}$
  - Tilt error < 100  $\mu\text{Radians}$



# MDA SBIR Roadmap

## Purpose

### Design & Fabricate On-Axis Nickel-Plated Be Telescope

- Using combined DT & CCP technologies to achieve
  - High performance optical system
  - Requiring no manual alignment
- **Phase I – Complete Sept, 2005**
  - Design hardware & tolerances
    - Configure hardware & interfaces to be consistent with, & optimized for, the two manufacturing processes
    - Develop tolerance budgets for each production stage
    - Plan prototype manufacturing process
- **Phase II**
  - Produce full scale prototype
    - Precision alignment features integral to hardware
    - Precision optical profiles true to alignment features
    - Alignment-free assembly process

## Phase III

- **Commercialization plan**
- **“Self-Aligning” Aspheres**
  - $\lambda/10$  P-V Aspheric components
  - With integral alignment reference surfaces
    - Centration to  $< 2.5 \mu\text{m}$
    - Tilt  $< 50 \mu\text{Radians}$